

HIGH-PERFORMANCE LONG YAGIS

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IF YOU ARE INTERESTED in vhf/uhf dx, you're also interested in high-performance Yagi antennas. This article describes the good features to look for when assessing a long Yagi, and how these features have been optimized in modern designs.

What are we looking for in a high-performance long Yagi? Forward gain is the most important single aspect of Yagi performance, so I'll begin with that. But keep in mind that gain isn't everything. What we really want is good performance in all respects.

Gain and boom length

Antenna gain should be proportional to the size of the antenna. If a bigger antenna doesn't out-perform a smaller one, there's something wrong with it. Increasing the gain of an antenna means increasing the size by using more Yagis, longer Yagis, or a bigger horn or dish on the higher-frequency bands. Doubling the antenna size will increase the gain by typically 2-2.5dB; in other words it won't quite double the gain. The reasons for failing to achieve the idealized increase of 3.0dB will depend on the type of antenna and the frequency.

A gain increase of 2-2.5dB makes a significant difference to dx performance. It won't be noticeable in strong-signal QSOs, but the essence of vhf/uhf dxing is that you're always prepared to work with weak signals at the very limits of propagation, where even 1dB can make all the difference. Even with stronger signals, more antenna gain will gradually pay off, in terms of more replies to CQ calls, less time spent cluttering up the frequency in large pile-ups, and more points in contests. We'll also see that more antenna gain can mean less interference to local stations. If you start from small beginnings, then doubling the size of your antenna won't be too difficult. For example you could replace a Yagi of 2m boom length by one that's 4m long. But the next step means going to two 4m Yagis, or one with an 8m boom. And each further step means re-doubling the size of the array! Even so, many amateurs (and an increasing number in the UK, I'm pleased to say) are prepared to do just that.

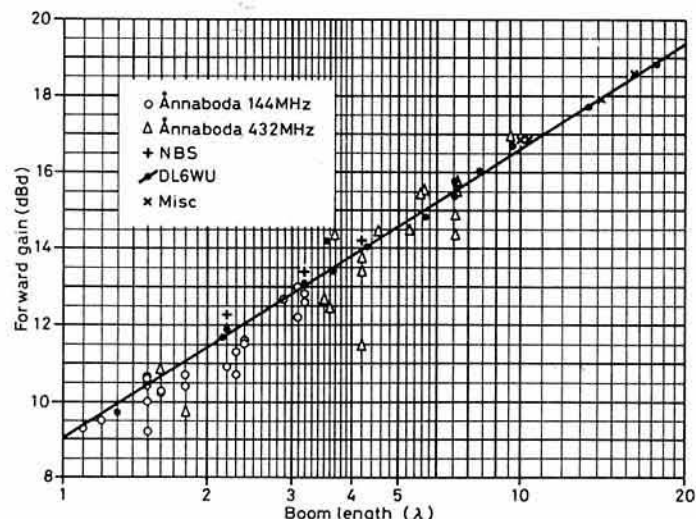


Fig 1. Forward gain is proportional to boom length

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I've already implied that the gain of a long Yagi should be proportional to boom length. Although doubling the length may not quite achieve the idealized gain increase of 3.0dB, the shortfall should be small, and each successive doubling of the length should produce a similar gain increase with no sign of flattening out. This is a reliable test of the 'goodness' of long Yagi designs. If a whole family of long Yagis can be created by simply extending the boom length and following consistent design rules for the element lengths and spacings along the boom, and the gains increase consistently in the right way, then every Yagi in that family should be a good one. At least one such family of modern long Yagis exists.

Fig 1 is part of my continuing collection of claimed and measured gain figures for 144MHz, 432MHz and 1.3GHz long Yagis, plotted against boom length in wavelengths. All gains in this article are expressed in dBd, ie decibels above a half-wave dipole [1]. With one or two honourable exceptions, the gains claimed by the antenna manufacturers lie far above the independent measurements of the same Yagis, and have not been included. Several conclusions emerge from detailed analysis of the data summarized in Fig 1:

1. Gain is proportional to boom length. The solid points and the straight line are from one consistent series of measurements, and verify the proportionality to almost 20λ. Variations between measurements from different sources obscure the trend but do not negate it.
2. Quads, loop-Yagis, "quagis", "parrot-perches" and "motleybeams" are all represented, but they do not stand out from the ordinary Yagis.
3. For a given boom length, the difference in gain between a good Yagi and a mediocre one is only a decibel or two.
4. The same gain can be achieved with various numbers of elements on the same overall boom length. The number of elements does affect many other characteristics of the antenna, and I'll say more about this later.
5. The Yagis represented by the solid points will be worth a closer look.

Radiation patterns

When assessing a Yagi design, you can get far more information from a critical study of the directional radiation pattern than you can from simple tables of claimed gain and front/back ratio. Fig 2 shows a typical pattern, calibrated 360° around the compass, and inwards in decibels. Maximum power is radiated at the peak of the main lobe; this point is always plotted at the top of the diagram (0°, 0dB). Radiated powers in other directions can be plotted down to typically 40dB below the peak of the main lobe. Although usually called a radiation pattern, Fig 2 could equally well be called a reception pattern, for antennas behave the same in receive and transmit modes.

For vhf/uhf dx working, the antenna should be horizontally polarized—not from mere convention, but because horizontal works better for dx. Thus the most important radiation pattern—the one you observe when you turn the rotator—is the pattern in the same plane as the Yagi. This is called the E-plane. The pattern in the H-plane (the vertical plane for a horizontally polarized Yagi) is very similar to the E-plane pattern. The longer the Yagi, the more alike the E-plane and H-plane patterns become, the main differences being that the E-plane pattern always has nulls at ±90° [2], and the H-plane pattern always has a slightly broader main lobe and higher sidelobe levels.

Fig 2 also summarizes the points to look for in a good radiation pattern. The main lobe is distinct, and the pattern is generally 'clean' with good suppression of minor lobes. The pattern should be symmetrical and there should be clean, deep nulls at ±90° in the E-plane—if not, there's something wrong with either the Yagi or the measurements [2].

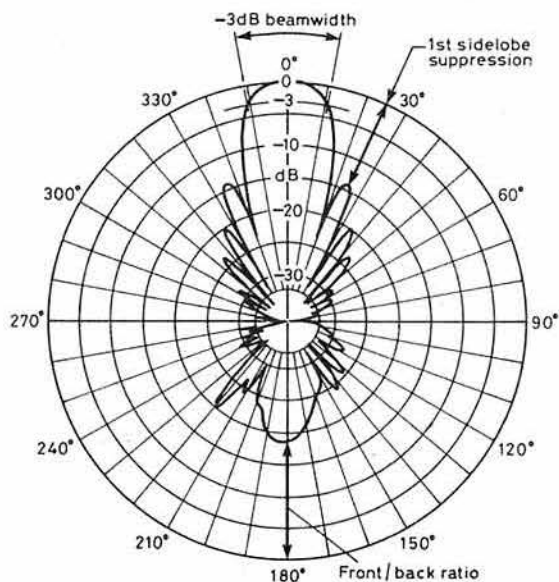


Fig 2. E-plane pattern of a good long Yagi. Note the general symmetry and the deep nulls at $\pm 90^\circ$

Low levels of minor lobes in the polar pattern are almost as important as gain. In fact the two features are closely related, since any beam works by concentrating rf energy into the wanted direction at the expense of radiation in unwanted directions. On receive, good suppression of the minor lobes means a stronger signal from the wanted direction, and less interference from stations in other directions. You can't judge the minor-lobe suppression by simple 'magic numbers' like front/back ratio. The problem with front/back ratio is that it's too easy to optimize that one aspect of performance while letting the other sidelobe levels run wild. A better general indicator of minor-lobe suppression is the level of the first sidelobes on either side of the main lobe. These 'rabbit ears' are present in all long Yagis, though in a good design they would be suppressed to about -15dB. But even first-sidelobe suppression is open to abuse. One well-known US manufacturer regularly claims "sidelobe" suppressions of 60dB, when what they really mean is front/side ratio. We've already seen that front/side ratio ought to be infinite [2], so "60dB" is nothing more than advertising hype.

A further word of warning when you look at the patterns of different Yagis: don't trust your first impressions. The whole appearance of the pattern can be altered by the calibration of the radial rings. Since there is no fixed convention, you *always* need to check how the rings are labelled down the 0° axis. In this article I have used a linear decibel scale going down to -40dB at the centre, on the grounds that a decibel scale reflects the response of our receivers and our ears, and measurements below -40dB are probably meaningless. This scale, or something very like it, is the type used by professional suppliers of antenna-range equipment. ARRL publications use a non-linear decibel scale which contracts towards the centre and tends to de-emphasize the minor lobes. Above all, beware of the linear power scale. Typically calibrated from 10 at the top to 0 at the centre (in plain numbers, not decibels), this scale compresses all the minor lobes into the centre and produces a sharp-looking main lobe. The linear power scale always flatters to deceive; so be warned.

Gain and beamwidth

The higher the gain of a beam, the harder it becomes to aim it in the right direction. The reason is very simple: higher gain is achieved radiating more energy in the forward direction, and that means radiating less energy in the unwanted directions—including the edges of the main beam. Beamwidth is conventionally quoted as the total angle between the -3dB points of the main lobe (Fig 2). As gain is increased, beamwidth *must* decrease [3]. You can't get away from this, but you can considerably ease your aiming problems by choosing a Yagi design which gives a well-shaped main lobe.

Fantasizing, the ideal would be the fan-shaped main lobe shown in Fig 3a, with maximum gain across the whole beamwidth for ease of aiming, and no sidelobes at all. Such perfection is not even attainable in theory; we have to accept that the edges of the main beam will always be rounded, and sidelobes will always be present.

Even so, there is no reason to accept a main lobe like the one in Fig 3b, which is sharply pointed and has less than 10dB of sidelobe suppression. If a Yagi has a pattern like that, there's something fundamentally wrong with

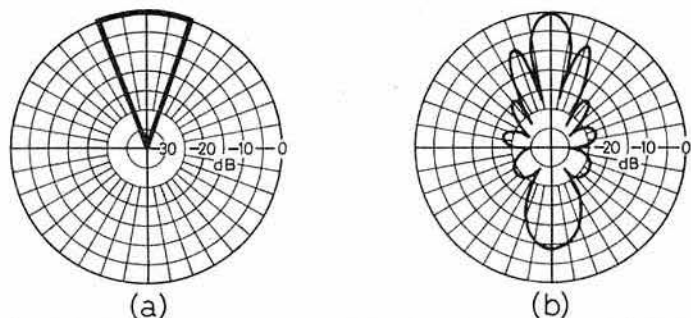


Fig 3. (a) Idealized radiation pattern, with flat-topped main lobe and no sidelobes at all. (b) Unacceptable radiation pattern, with pointed main lobe and excessive side and back lobes

it, no matter how high the maximum gain may be. It isn't just a matter of aesthetics; a beam with a pointed main lobe is a real pain to use. It's too difficult to peak a station right on the point of the main lobe, and too easy to peak on a sidelobe by mistake. The best achievable shape for the main lobe is shown in Fig 2; there is no doubt about finding the main lobe, yet its fairly flat nose makes peaking the signal quite uncritical.

Optimized long Yagis

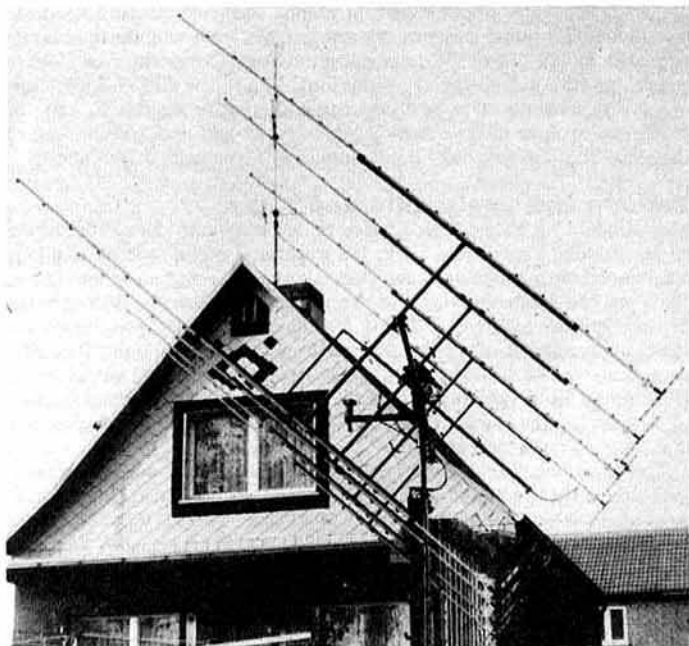
To sum up all the desirable aspects of antenna performance, an optimized Yagi will have:

- high forward gain, for its boom length;
- a generally clean polar pattern (in particular, first sidelobes at about -15dB);
- a well-shaped main lobe which causes no undue problems in aiming.

There are no fundamental conflicts between good performance in all of these areas, provided we don't go blindly chasing the maximum possible gain. In a modern optimized long Yagi, all the above objectives can be achieved together.

Modern long Yagi designs have evolved through a long process of trial and error—mostly error! Designs for shorter Yagis have been adapted and extended, in the hope of producing workable longer Yagis with higher gain. The early work on long Yagis was done in the 'fifties and 'sixties by investigators who seemed largely unaware of each other's activities and pursued different but parallel paths. This tangled history can be straightened out into some kind of logical progression which forms a starting point for further development. The most successful modern Yagi designers have done this, and have built upon the work of their predecessors rather than starting yet again from scratch. Thus there has evolved a definite "mainstream" of long Yagi design.

The mechanical dimensions required for optimum performance are usually found by experiment. Countless thousands of man-hours and tons



DL9KR has developed a successful variant of the DL6WU Yagis, shown here in the moonbounce array at Y23TI

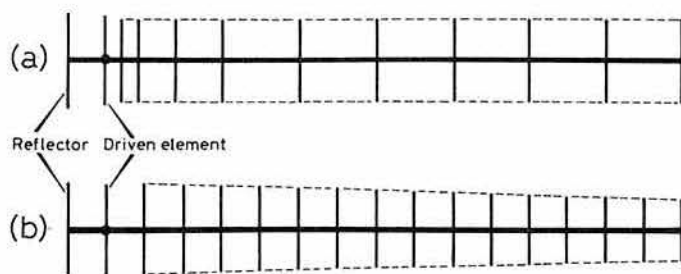


Fig 4. Single-optimization schemes. (a) Optimize tapering of director spacings, keeping all lengths the same (eg W2NLY/W6QK1). (b) Optimize tapering of director lengths (exaggerated), keeping all spacings the same (eg NBS)

of aluminium have gone into the optimization of high-performance long Yagis. Computer analysis is increasingly used to assess potential improvements, and can save a great deal of experimental effort, but successful computer optimization is a lot harder than it might seem [4]. Yagi design still begins with ideas in someone's head, and ends with measurements on real antennas.

It's remarkably easy to build a Yagi which behaves something like a beam, but incredibly difficult to measure the difference between a good beam and a poor one. And I do mean 'incredibly'; until you've tried your hand at gain and pattern measurement, you cannot believe how difficult it is! For measurements on practical vhf/uhf Yagis, even the highest available professional standards are only just good enough. Unless your own measurements are as good as that, you're wasting your time. You will require access to a large, uncluttered test range for considerable period. For amateurs, this implies either weekend access to an existing professional range, or a major co-operative effort such as the regular measurement sessions at US vhf conventions, or the epic weekend at the 1980 convention at Annaboda in Sweden [5].

Throughout the whole history of amateur-band antennas, there have been frequent claims of 'miracle' beams which break the gain/size barrier. Electrically small (eg two-element) beams can beat the odds to a small extent, but the reasons for this are clearly understood, and they do not apply to long Yagis. Unfortunately, since accurate gain measurements are so difficult, it's all too easy for people to obtain results which they proclaim with fervour and total sincerity, but which are in fact wrong. Sure enough, you'll never be happy with an antenna unless you have faith in it; but faith alone won't get you the dx!

Far more is known about Yagis using simple rod-type dipole elements than about other types of Yagi using loops or more elaborate element shapes. The latter may offer slightly higher theoretical gain, but even in theory this advantage dwindles away as the Yagi gets longer. The existing body of knowledge about conventional elements can provide only hints about the behaviour of other element shapes, so the designer who chooses to use unconventional elements is starting again from scratch. In accurate comparisons [5], few of the more elaborate Yagis have come even close to competing with well-designed conventional Yagis. The G3JVL loop Yagis are a rare example of a well-developed alternative approach, and the performance of the later versions is running neck-and-neck with the best of the plain Yagi designs; but I don't think they've actually drawn ahead.

Uniform and singly-optimized Yagis

Mainstream long Yagi design is based on some definite ideas about how a successful long Yagi should work. It's sometimes useful to think of a long Yagi launching a travelling wave along its structure and away into space. Thus you can divide the Yagi into two parts: a 'launcher' consisting of the driven element, reflector and first few directors; and a travelling-wave structure consisting of all the rest of the directors. Although that isn't necessarily the best all-purpose description of how a Yagi works [6], it eliminates a lot of random cut-and-try by focusing on those combinations of element lengths and positions that show the most promise of launching and propagating a travelling wave.

This straightened-out, shortened and simplified story of mainstream long Yagi design starts with the work of Ehrenspeck and Poehler [7], who made a major investigation of "uniform" long Yagis with all directors of the same length and equally spaced along the boom. Short uniform Yagis can work very well, but they fail to achieve the expected increase in gain with boom length. In other words, uniform long Yagis are an evolutionary dead end.

The next step forward came from investigations of the effects of tapering. In the language of long Yagi design, "tapering" has two meanings. Tapering the element spacings means that successive directors

are spaced further and further apart, going forwards along the boom (Fig 4a). Tapering the element lengths means that each director is shorter than the one before (Fig 4b). The two kinds of tapering should have very similar effects on a travelling wave. So, to keep the experimental work within manageable bounds, it seemed sensible to optimize either director spacing or director length, leaving the other one constant at some initially chosen value. This generation of long Yagis has since been called "singly-optimized".

Most experimenters have agreed that tapering should be quite pronounced in the launcher section, close to the driven element. Directors further along the boom need not be so strongly tapered. Tapering of spacings was investigated by W2NLY and W6QK1, who developed some quite successful Yagis in which all directors were the same length, and the director spacing initially increased and then became constant. The optimum value for this constant spacing seemed uncritical between 0.3λ and 0.4λ , though the wider spacings obviously involve fewer elements and less windload [8].

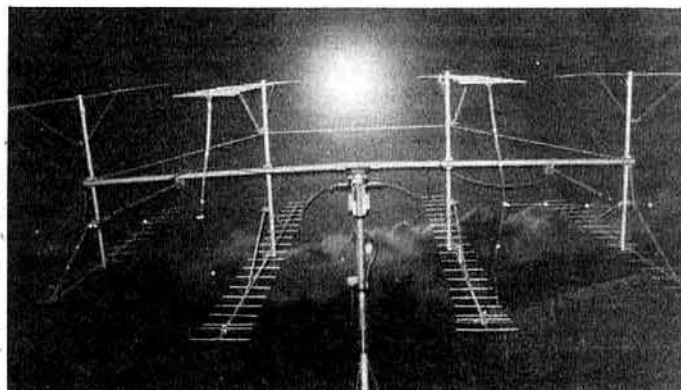
Tapering of director lengths, with the spacings held constant, is the basis of the well-known "NBS" Yagis, derived from the work of Peter Viezbicke of the US National Bureau of Standards in the 'fifties [9]. This mammoth effort included full investigations of length-tapering schemes and of the effects of different element diameters and mounting methods. It culminated in a set of designs including long Yagis with boom lengths of 3.2λ and 4.2λ . Joe Reisert, W1JR and others have explained how to design NBS beams from Viezbicke's charts [10]. NBS long Yagis are good, but they cannot be extended; and much has happened in the three decades since they were developed.

The two single-optimization techniques produced the best long Yagis available at the time, and these designs have been enshrined in the amateur literature ever since. But single optimization failed to produce Yagis which can be extended satisfactorily to meet today's requirements for longer Yagis with higher gain. So the next step was to combine the experience from tapering either the lengths or the spacings, and to taper them both. W2NLY and W6QK1 found some improvement in bandwidth from length-tapering their spacing-optimized designs. At about the same time as the single-optimization work was going on, Carl Greenblum independently investigated double-tapering and produced his own general guidelines on element lengths and spacings. Together, all these experiments formed the basis of some classic amateur Yagi designs of the 'sixties and 'seventies [11].

Double optimization

The most promising of the modern-day long Yagi designs come from Günter Hoch, DL6WU. He has thought carefully about ways of improving earlier designs, and his extensive experimental results have been obtained using professional test facilities. DL6WU considered first the director-spacing aspect of tapering. W2NLY and W6QK1 showed that this is important in the launcher section, but can be stopped once the spacing has been gradually increased to about 0.4λ . Further increases in spacing in the travelling wave part of the Yagi are counter-productive. This spacing scheme seemed close enough to optimum, so DL6WU turned his attention towards optimizing the element-length tapering as well. The result was to be a highly successful family of "doubly-optimized" long Yagis [12].

The simplest form of director length tapering would be to make each director shorter than its predecessor by a constant amount. This works if the Yagi is not extended too far, but eventually the forward gain bleeds away into increased levels of minor lobes. If you extend the Yagi far enough, subtracting a constant amount from each successive director, you eventually arrive at a director length of zero—a dead end, if ever



Tonna Yagis follow the company's own system of tapering both element lengths and spacings. This array of eight 21-elements has been converted for open-wire feed

there was one! DL6WU's answer to that problem is one of those brilliant ideas which seem so obvious in hindsight; taper each successive director length by a constant fraction. This logarithmic tapering makes the director lengths decrease quite sharply in the launcher section, but less markedly further along the array. No matter how far the Yagi is extended, the director lengths can never reach zero, and the logarithmic tapering seems to confer some degree of frequency-independence. Various people have come close to this approach in the past, but to my knowledge only DL6WU has spelt it out as a design rule, and then followed it through to develop a whole family of successful long Yagis.

The shortest in the DL6WU family of long Yagis consists of only the launcher section with its gradually increasing director spacings. Longer Yagis can then be designed simply by adding more directors at a constant spacing of 0.4λ , with the appropriate logarithmic tapering of element lengths. The performance of the DL6WU Yagi is a tribute to Günter Hoch's clear thinking about the problem. Without any further optimization, all the Yagis built from DL6WU's design charts have clean patterns and well-shaped main lobes, and therefore their forward gains are as high as their chosen boom lengths will allow. These are the long Yagis represented by the solid points in Fig 1, and the straight line shows every promise of extending beyond 20dBd—that is, if you care to build a Yagi 24 wavelengths long! Perhaps the most remarkable feature of the whole family of DL6WU Yagis is the way that the patterns remain so consistent as the Yagis are extended. Naturally the main lobes become narrower as the Yagis become longer, but the patterns remain clean and the suppression of the first sidelobes remains consistently good at about 15–20dB. In short, DL6WU long Yagis show every sign of working properly.

Goodbye to all that

The success of the DL6WU Yagi has demolished several cherished myths and moans.

"Long Yagi can't be extended." Sure they can, if you do it right!

"Ordinary Yagis don't work on microwaves." Oh yes, they do! The longest Yagi on Fig 1 were all developed on 1.3GHz. I'm not suggesting that Yagis are the best antennas for the higher microwave bands, but there's absolutely no reason why they shouldn't work if scaled properly to the wavelength.

"Element dimensions for long Yagis are extremely critical." If some people were to be believed, the element lengths of the 1.3GHz Yagis would each need to be accurate to 0.1mm. In fact the logarithmic director taper appears to be very forgiving of constructional errors.[13].

"Bandwidths of long Yagis are extremely narrow." With logarithmic tapering, the Yagi itself is quite wideband [13]; the frequency-conscious part is usually the method of matching the feedline to the driven element.

"You can't feed a long Yagi with a simple dipole." Yes we can, and we don't need help from quad-loops, log-periodics or ZL-specials either!

Why not try one?

If you are interested in building some DL6WU Yagis, I strongly recommend you read Günter Hoch's 1982 article [12]. It contains a set of simple design charts of element lengths and spacings along the boom. Element diameter is also important, because it affects the electrical lengths of the elements, and so too does the way the element is mounted on the boom. DL6WU covers all these points, and casts many valuable sidelights on the practical aspects of building long Yagis. A microcomputer program for the design of DL6WU Yagis is obtainable via the RSGB's *VHF/UHF Newsletter* [14]. Yagis based on the work of DL6WU are now appearing worldwide, both from individual amateurs and from professional manufacturers. I recommend them highly.

What next?

Günter Hoch has eliminated most of the faults of the earlier singly-optimized Yagi designs, to produce a family of excellent all-round performers. I don't suppose the DL6WU designs are the ultimate long Yagis, any more than their predecessors were, but they are the definitive starting point for anybody working in the main stream of long Yagi development today.

There are two ways forward from here; we can optimize the general design methods for long Yagis, or we can intensively optimize individual Yagis for specific purposes. That isn't an either/or choice. Eventually, we need to do both. Intensive optimization will certainly be a source of good designs, and already some very promising computer-optimized Yagis based on DL6WU's work are being built and evaluated in the USA [15]. But intensive optimization imposes its own strict terms: you must either take the whole design and copy it exactly, or leave it alone. If you try to adapt the design to suit your own requirements, you've actually made a different Yagi and have "broken the spell" of the optimization. In my view, our ultimate goal should still be to optimize the design method itself. That way, we can obtain optimum performance from any long Yagi we choose to design.

Notes and references

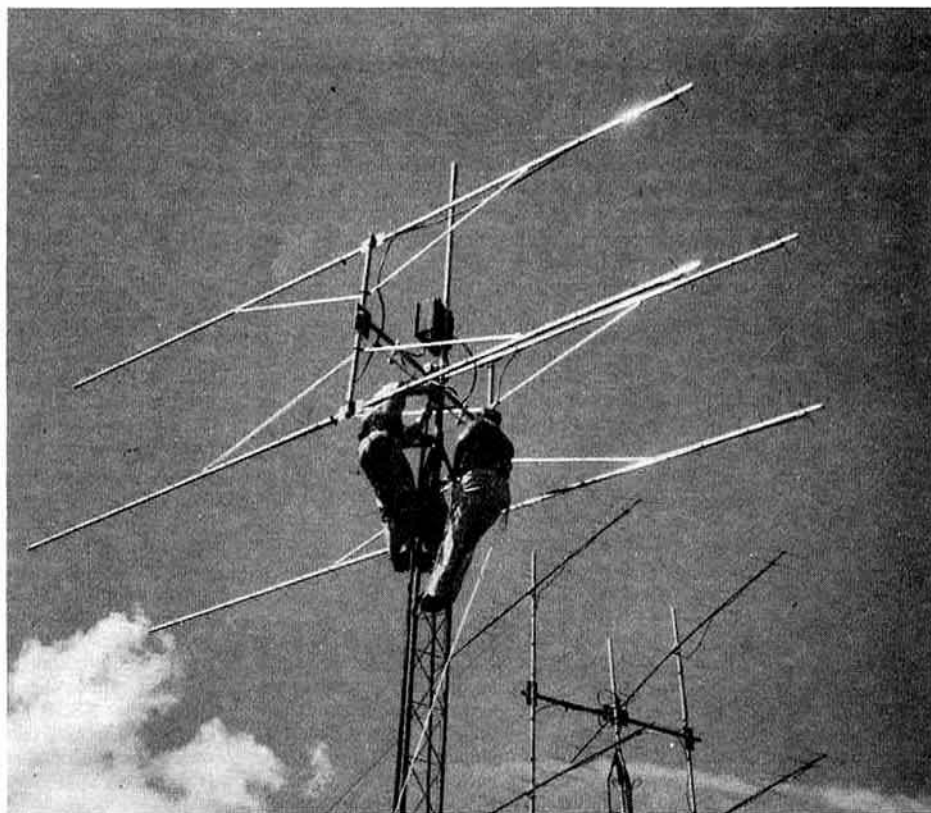
[1] Gain figures are sometimes quoted in decibels above a dipole (dBd), and sometimes in decibels above isotropic (dBi). dBd is easy to understand: you put your new beam in place of the old half-wave dipole, and get xdB stronger signals when you point the beam the right way. But even a half-wave dipole radiates better off its sides than off its ends, so it has some gain over an isotropic antenna which radiates equally poorly in all directions; 2.15dB more gain, in fact. So the gain of an antenna expressed in dBi looks 2.15dB better than the gain of the same antenna in dBd.

Don't be put off by the fact that a dipole exists, while a true isotropic antenna doesn't. They are both equally useless for *practical* gain measurement! dBd and dBi are merely concepts, and you need to be comfortable with both of them. Just remember that dBi looks 2.15dB bigger than dBd, but the antenna itself doesn't care.

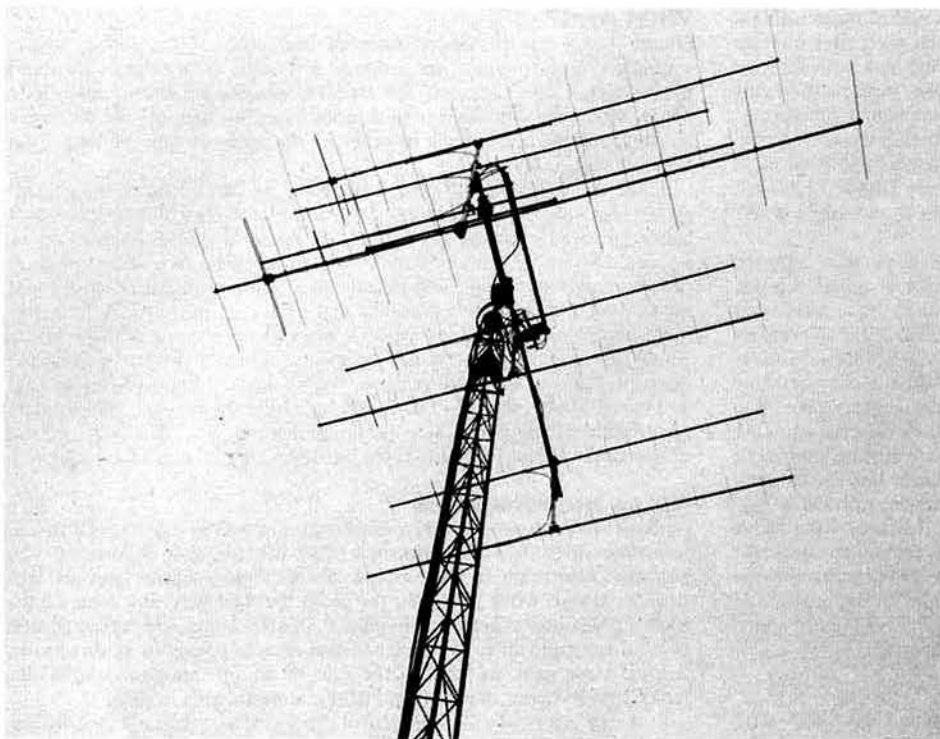
Gains of mobile antennas are sometimes quoted in dB above a quarter-wave, but that's not relevant to Yagis.

[2] At $\pm 90^\circ$ in the E-plane, you are viewing the individual Yagi elements end-on. Since the elements are all basically dipoles, and dipoles don't radiate off their ends, the Yagi as a whole won't radiate in those directions either.

Skewing of the measured pattern may indicate some imbalance in the driven element, causing sideways radiation due to rf currents running up



WA2AAU and WA2SPL get to grips with four 31-element DL6WU Yagis for 432MHz. In the background are four 15-element NBS Yagis for the USA 220MHz band



In an unusual asymmetrical array, DL6WU has stacked two 11-element 144MHz Yagis of his own design with six of the highly-respected K2RIW 19-element Yagis for 432MHz

and down the metal boom. Even if there is nothing wrong with the antenna, apparent asymmetry could be caused by stray reflections on the antenna test range; this can easily be checked by turning the antenna over.

[3] Doubling the boomlength of a long Yagi, and hence nearly doubling the gain, would reduce both the E-plane and H-plane beamwidths to about 70 per cent of their previous values. This follows from the so-called Kraus formula relating gain to E-plane and H-plane beamwidths:

$$B_E \times B_H = 25000 / (\text{antilog } G/10)$$

where the beamwidths are in degrees and G is in dBd. Since the two beamwidths are almost equal for a long Yagi, you can estimate them both with reasonable accuracy.

The Kraus formula is *not* accurate enough to estimate the gain from the beamwidths. The presence of sidelobes, together with quite minor inaccuracies in beamwidth measurement, can totally blur the difference between a good Yagi and a poor one.

[4] Yagis developed by maximizing only the forward gain tend to be poor in all other respects. Fortunately, cut-and-try experimenters always run out of time, enthusiasm and aluminium before they can completely ruin the Yagi's performance. But a computer will pursue the process to its logical and absurd conclusion, unless you tell it what you really want. A successful computer optimization program needs to take account of all the other performance criteria I've been discussing in this article.

[5] At the 1982 RSGB VHF Convention, SM5CHK gave a graphic account of the effort involved in staging a gain-measurement weekend, starting from an empty field. To summarize; allow at least one day for building and checking the test range. As well as needing two crank-up, tilt-over towers, you'll have to build two long mesh fences to suppress stray reflections. Allow one more day (preferably of Scandinavian summer length) to do the measurements, plus at least two years to recover.

Let's be quite clear about the amateur's standing in this area. The technical concepts are certainly not beyond our grasp; many amateurs in their spare time reach higher levels of understanding than some full-time professionals ever will! It's just that good quality antenna performance measurements make heavy demands in areas where our amateur resources are the least, namely physical facilities and time. If we admit that our back-garden measurements are not reliable, then at least it shows that we understand how measurements *should* be done.

[6] The travelling wave explanation is helpful when looking at Yagis in broad terms, but it doesn't take much account of the fact that a Yagi is actually an array of distinct elements. When attempting to explain the performance of a Yagi with a particular set of element dimensions and spacings, it's better to take the latter view. A vector diagram of the currents in the individual elements should show a regular sequence of phase differences between successive directors, with each director contributing fully to the forward radiation of the whole array. See "Yagi antennas",

of the W2NLY/W6QK1 design, and very good it was too, for its time.

[9] "Yagi Antenna Design", P P Vezibicke. *NBS Technical Note* 688, December 1976. Almost twenty years elapsed before this work was published! In the meantime, the 'leaked' 4-2λ NBS design became well-known as the W0EYE Yagi.

[10] "How to design Yagi antennas", J H Reisert, W1JR. *Ham Radio* August 1977, pp22-30.

[11] "Notes on the development of Yagi arrays", C Greenblum. *QST*, August and September 1956. Various Yagis developed from Greenblum's work for the Telrex company were subsequently described in *QST* and other ARRL publications by Ed Tilton, W1HDQ.

[12] "Extremely long Yagi antennas", G Hoch, DL6WU. *VHF Communications* 14, March 1982, pp131-138. (For earlier work by DL6WU, see [6] and also "More gain from Yagi antennas", *VHF Communications* 9, April 1977, pp204-211.)

If you can read Dutch, the best current reference to the work of DL6WU is "Zelf Ontwerpen en Bouwen van VHF en UHF Antennes" by DL6WU and PA0MS, published by VERON, the Dutch national amateur radio society. The forthcoming ARRL *uhf/microwave handbook* will include a whole chapter by DL6WU.

[13] The forgiving nature of the logarithmic taper can be exploited to simplify construction. In principle the director lengths should decrease gradually, with no two the same. In practice, beyond the launcher section close to the driven element, all the different lengths can be rounded-off to make a series of equal-length groups. Almost all the element lengths for a 1.3GHz DL6WU Yagi can be cut to the nearest millimetre in groups of two, three or more, and careful measurements show hardly any difference in performance [12].

I have also investigated the bandwidth and dimensional tolerance of the DL6WU 49-element Yagi for 1.3GHz using a reliable computer model. The computed gain bandwidth of the Yagi itself (as distinct from its matching network) is more than 100MHz between -1dB points! And the logarithmic taper structure does seem extraordinarily tolerant of both random and systematic errors in director lengths. If all the elements are too long or too short by as much as 1mm, or if the lengths vary randomly within the same range, the only significant changes are in minor features of the pattern. Thus the computations confirm that the variations in gain, first sidelobe levels and f/b ratio would be very difficult to measure on a test range, and would be quite undetectable on the air.

[14] Program listings are available in either Microsoft/GW Basic or BBC Basic from: RSGB *VHF/UHF Newsletter*, PO Box 73, Hereford. Please enclose an A4-size sae and specify which listing you require. The program may also be available on disc; please enquire.

[15] "VHF/UHF World", Joe Reiseart, W1JR, *Ham Radio* December 1986.